Analysing the Relationship Between Skin and Formation Damage of an Oil Well (Time Depended)

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Abstract: The concept of skin and formation damage play a vital role in productivity of an oil well. The objective of this study is to introduce the effect of skin into the well flowing equation in transient state. The effect of formation damage zone on the well flowing pressure was introduced to the original solution of diffusivity equation by considering three scenarios. In the first scenario it was assumed that oil is flowing through the reservoir with average (effective) permeability. In the second scenario it was assumed that the oil is flowing with the permeability of reservoir till the boundary of formation damage zone and within the altered zone, oil is flowing with the permeability of damage zone. The third scenario is similar to the second scenario, however it was assumed that the oil is flowing within the altered zone with an average permeability. By considering the difference between calculated reservoir permeability for all three scenarios and assumed values, scenario three was selected as the most suitable way to introduce the effect of skin in to the well flowing equation in transient condition.

Keywords: Formation Damage, Skin, Permeability, Altered Zone, Well Flowing Pressure

1. Introduction

Concepts of skin and formation damage come along with the well testing analysis. Van Everdingen [1] defined the skin as the additional pressure drop in the near wellbore area that results from the drilling, completion and production practices used. According to McPhee [2] "Formation Damage can be defined as any reduction in near well-bore permeability as a result of drilling, completion, production, injection, attempted stimulation or any other intervention". Impacts of skin and formation damage are often considered as same but it is vital to recognize these two are different parameters [2 and 3].

Well testing data is the key data used to calculate the reservoir permeability and skin factor. Interpretation of the well testing data is done with use of the diffusivity equation which is used to describe the fluid flow through porous media as stated in equation 1.

$$\frac{1}{r}\frac{\partial}{\partial r}\left[\frac{k\rho r}{\mu}\ \frac{\partial p}{\partial r}\right] = \emptyset\rho c\frac{\partial p}{\partial t} \quad \text{.......………….... (1)}$$

Since the reservoir is in the transient condition during the well testing, solution for the diffusivity equation is derived for infinite outer boundary condition and can be presented as equation 2.

$$p\ = p_i + \ \frac{q_{sc}B\mu}{4\pi kl}Ei\left[-\frac{\emptyset\mu c_t r^2}{4kt}\right] \quad \text{……….(2)}$$

where; r – radius, p – pressure, k – permeability, μ - viscosity, Ø – porosity, t –time.

Equation 2 can be applied for an ideal well where there is no formation damage zone and no effect of skin. Hawkins [4] derived the equation, equation 3, to determine the effect of skin (S) in steady state.

$$S = 2\left(\frac{k_e}{k_a} - 1\right)\ln\frac{r_a}{r_w} \quad (3)$$

Equation 4, which uses to calculate the well flowing pressure at well bore (P_{wf}) is derived by combining the equation 2 and 3.

$$P_{wf} = p_i + \frac{q_{sc}B\mu}{4\pi kh}\left\{Ei\left[-\frac{\emptyset\mu c_t {r_w}^2}{t}\right] + 2\left(\frac{k_e}{k_a} - 1\right)\ln\frac{r_a}{r_w}\right\} \quad (4)$$

However, the use of this equation for transient condition is questionable as the effect of skin is introduced in steady state condition. Several researches have been conducted to investigate the effect of skin in transient condition. Most of them are highly based on mathematical models and derivations. For instance, Wattenbarger [5] investigated the skin effect with finite difference method and Van Everdingen [1] tried to derive the skin using Laplace transformation.

The primary objective of this research is to introduce the effect of skin into the general well flowing equation and investigate the relationship between skin and the formation damage of a well using the developed equation.

2. Methodology

Methodology used in the research mainly consisted with two parts.

Part 1: Develop a method to introduce the effect of the skin to the transient well flow equation.

Part 2: Analyze the relationship between properties of damage zone and the skin in transient condition using the developed equation.

2.1 Construct reservoir model

To calculate the well flowing pressure data several reservoir models were constructed by varying ratio between radius of the formation damage zone and radius of the wellbore and ratio between permeability of the reservoir and permeability of damage zone. Other parameters used for the calculations are presented in Table 1.

2.2 Develop a method to introduce the effect of the skin to the transient well flow equation

When introducing the effect of skin to the well flowing equation, three scenarios were considered.

Table 1 : Properties used for the reservoir model

Initial reservoir pressure (psi)	p_i	3500
Production rate (stb/day)	q_{sc}	1500
Porosity	Ø	18.00 %
Formation volume factor (rb/stb)	B	1.2
Net formation thickness (ft)	h	20
Viscosity (cp)	μ	1
Total compressibility (psi^{-1})	C_t	1.50×10^{-5}
Well bore radius (ft)	r_w	0.25
Permeability of the reservoir (mD)	k_e	300
Permeability of altered zone (mD)	k_a	100
Radius of altered zone (ft)	r_a	0.75
Reservoir rock		Sand stone

Scenario 1:

Due to the formation damage, it can be considered that the reservoir consisted with two zones as presented in

Figure 1. In this scenario, it was assumed that the oil is flowing towards the well with the average permeability of two zones. The equation used to calculate the well flowing pressure is presented in equation 5.

$$P_{wf} = p_i - \frac{q_{sc}B\mu}{4\pi k_{avg}h} Ei\left[\frac{\emptyset\mu c_t r^2}{4k_{avg}t}\right] \ldots\ldots (5)$$

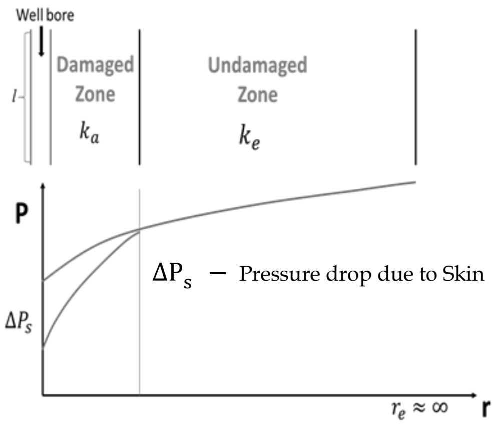

Figure 1: Vicinity of wellbore

Scenario 2:

It was assumed that oil in the revoir is flowing towards the well with the reservoir permeability (k_e) up to the radius of damage zone (r_a). Within the damage zone, oil is following with the permeability of damage zone (k_a). Following steps were followed to derive the equation used in this scenario.

First, it was assumed that the permeability of the damage zone as well as the undamaged zone is equal to the original reservoir permeability (k_e)

The pressure at the boundary of altered zone (P_a) was obtained by substituting relevant r = r_a to equation 2.

$$P_a = P_i - \frac{q_{sc}B\mu}{4\pi k_e h} Ei\left[\frac{\emptyset\mu c_t r_a^2}{4k_e t}\right] \ldots\ldots\ldots\ldots (6)$$

Pressure at the boundary of well bore (P'_w) was obtained by substituting relevant r = r_w to the equation 2.

$$P'_w = P_i - \frac{q_{sc}B\mu}{4\pi k_e h} Ei\left[\frac{\emptyset\mu c_t r_w^2}{4k_e t}\right] \ldots\ldots\ldots (7)$$

The pressure difference within the damage zone (ΔP_1) was obtained as equation 8.

$$P_a - P'_w = \Delta P_1 = \frac{q_{sc}B\mu}{4\pi k_e h}\left\{Ei\left[\frac{\emptyset\mu c_t r_w^2}{4k_e t}\right] - Ei\left[\frac{\emptyset\mu c_t r_a^2}{4k_e t}\right]\right\} \ldots\ldots\ldots\ldots\ldots (8)$$

Then, it was assumed that the oil is flowing towards the well with a permeability of damage zone (k_a). Pressure difference within the damage zone (ΔP_2) was obtained in the same manner followed in above step.

$$P_a' - P_w'' = \Delta P_2 = \frac{q_{sc}B\mu}{4\pi k_a h}\left\{Ei\left[\frac{\emptyset\mu c_t r_w^2}{4k_a t}\right] - Ei\left[\frac{\emptyset\mu c_t r_a^2}{4k_a t}\right]\right\} \ldots (9)$$

Additional pressure drop (ΔP_3) , presented in figure 2, due to alteration of the permeability was calculated by subtracting equation 9 by equation 8

Final well flowing pressure (P_{wf}) was calculated by;

$$\mathbf{P_{wf} = P_w{}' - (\Delta P_2 - \Delta P_1)}$$

$$\mathbf{= P_w{}' - \Delta P_2 + \Delta P_1}$$

$$P_{wf} = P_i - \frac{q_{sc}B\mu}{4\pi k_e h} Ei\left[\frac{\emptyset\mu c_t r_w^2}{4k_e t}\right] - \frac{q_{sc}B\mu}{4\pi k_a h}\left\{Ei\left[\frac{\emptyset\mu c_t r_w^2}{4k_a t}\right] - Ei\left[\frac{\emptyset\mu c_t r_a^2}{4k_a t}\right]\right\} + \frac{q_{sc}B\mu}{4\pi k_e h}\left\{Ei\left[\frac{\emptyset\mu c_t r_w^2}{4k_e t}\right] - Ei\left[\frac{\emptyset\mu c_t r_a^2}{4k_e t}\right]\right\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Scenario 3:

The procedure was same as in scenario 2. Here it is assumed that the oil is flowing with an average permeability (k_{avg}) value within the damage zone instead of the permeability of damage zone (k_a).

Then equation 10 was obtained by substituting k_{avg} for k_a in equation 9.

$$P_{wf} = P_i - \frac{q_{sc}B\mu}{4\pi k_e h} Ei\left[\frac{\emptyset\mu c_t r_w^2}{4k_e t}\right] - \frac{q_{sc}B\mu}{4\pi k_{avg} h}\left\{Ei\left[\frac{\emptyset\mu c_t r_w^2}{4k_{avg} t}\right] - Ei\left[\frac{\emptyset\mu c_t r_a^2}{4k_{avg} t}\right]\right\} + \frac{q_{sc}B\mu}{4\pi k_e h}\left\{Ei\left[\frac{\emptyset\mu c_t r_w^2}{4k_e t}\right] - Ei\left[\frac{\emptyset\mu c_t r_a^2}{4k_e t}\right]\right\} \quad \text{……………………………………(11)}$$

2.3 Calculation of well flowing data

The well flowing pressure with respect to the time elapsed were calculated by substituting the parameters of above constructed model to the equation developed in section 2.2.

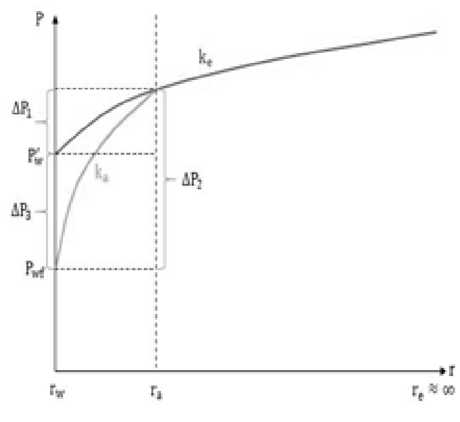

Figure 2: The resultant pressure variance of the reservoir

2.4 Analyzing of well flowing data

Graphs of pressure data (obtained from section 2.3) vs time elapsed were plotted. From the gradient of the graphs reservoir permeability was calculated.

2.5 Verification of equation

If the reservoir permeability (k'_e) value calculated in section 2.4 is equal to the assumed reservoir permeability (listed in Table 1), equation developed in section 2.2 was concluded as acceptable.

2.6 Analyze the relationship between skin and the properties of damage zone

To find a relationship between properties of damage zone and the skin, skin factor was calculated for several models constructed in section 2.1.

3. Results and discussion

Scenario 1 was failed during the verification step. Difference between assumed permeability value and the permeability value calculated in section 2.4 is very high for all the models constructed as shown in Figure 3. Other than the difference between calculated and assumed permeability values, this method gave a zero value for skin factor for all reservoir models. Zero skin value is impossible since we have defined a damage zone in each and every model. Therefore this scenario was rejected.

Deviations of the calculated permeability value from assumed permeability for scenario 2 are shown in Figure 4. It can be seen that the difference tends to increase when the ratio $\left({}^{r_a}/_{r_w}\right)$ increase for reservoir models which have higher reservoir permeability value than that of damage zone. When the damage zone has a higher permeability than that of reservoir, difference is negligible even for higher ratios of (r_a/r_w).

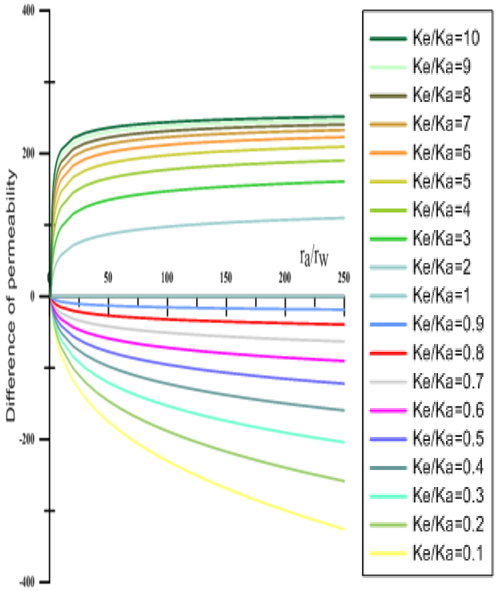

Figure 3 : Permeability difference for Scenario 1

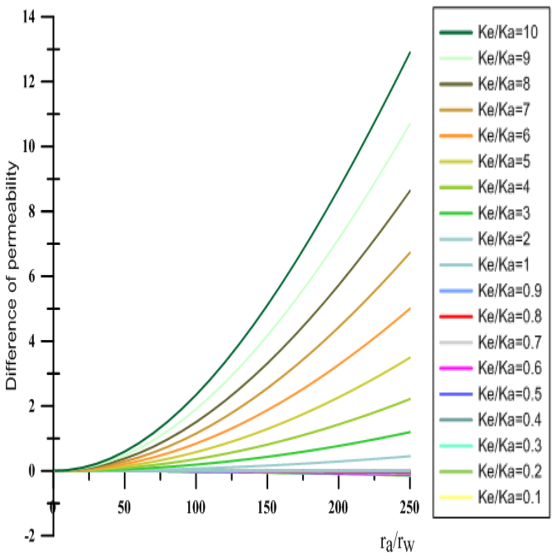

Figure 4 : Percentage of deviation of calculated permeability values in scenario 2

Figure 5 shows the relationship between skin factor and the properties of damage zone for scenario 2. It illustrates the variation of the skin factor with respect to the ratio between radius of damage zone and radius of wellbore and ratios between permeability of reservoir and permeability of damage zone.

Variation of the calculated permeability value with respect to the assumed value in the models for the scenario 3 is presented in Figure 6. Same trend observed in scenario 2 can be observed here.

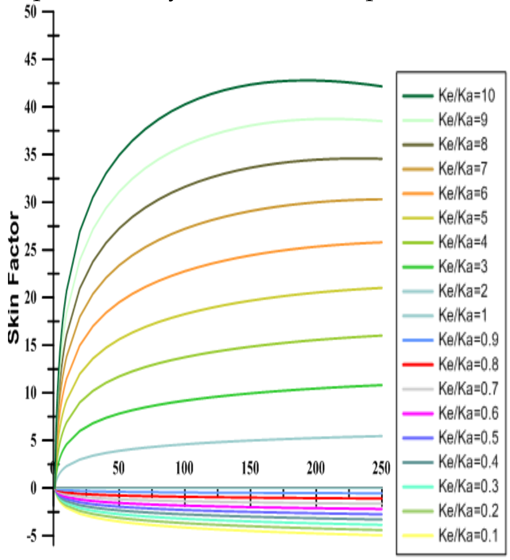

Figure 5: Skin vs $\mathbf{r_a/r_w}$ with respect to $\mathbf{k_e/k_a}$ in scenario 2

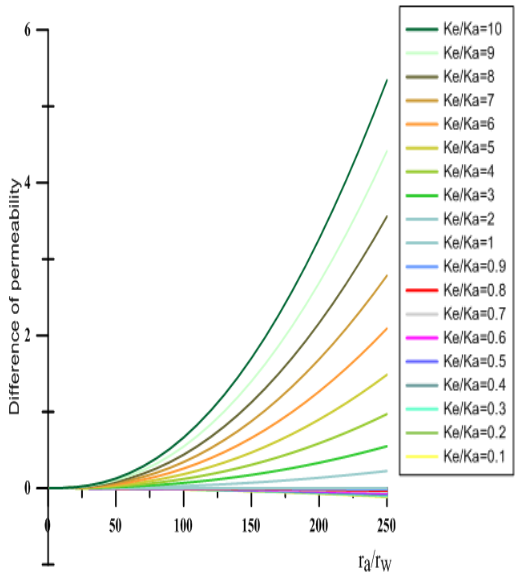

Figure 6: Percentage of deviation of calculated permeability values in scenario 3

Figure 7 illustrates the variation of the skin factor with respect to the ratio between radius of damage zone and radius of wellbore and ratios between

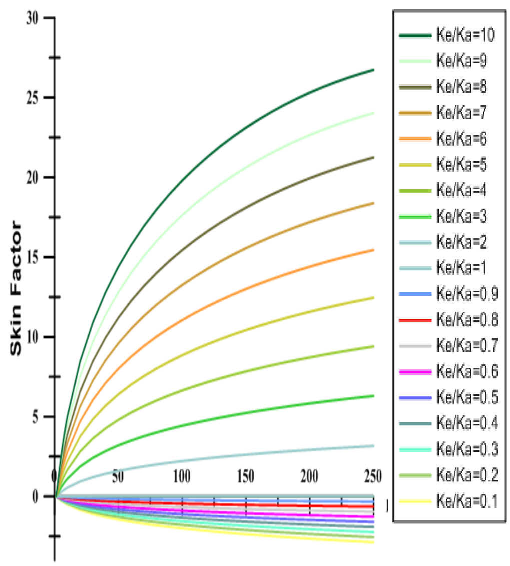

Figure 7: Skin vs r_a/r_w with respect to values of k_e/k_a in scenario 3

permeability of reservoir and permeability of damage zone for scenario 3.

According to the results of scenario 2 presented in Figure 4 and results of scenario 3 presented in Figure 6, the maximum deviation of permeability from the assumed value was noted when $\frac{r_a}{r_w}$= 250 for both cases. Figure 4 indicates the percentage of permeability difference between calculated and the assumed values for scenario 2 for this case, when the k_e/k_a = 10 is around 11% while for scenario 3 it is around 5%. This analysis shows that the scenario 3 gives least error in the back calculation.

According to the skin calculation scenario 2 ,presented in Figure 5, gives a maximum negative value of -5 while scenario 3, presented in figure 7, gave -2.5 for the same values of r_a/r_w and k_e/k_a. Value of skin factor practically varied between -5 to infinite. Results of both scenario 2 and 3 are compatible with the field results.

4.0 Conclusion

In scenario 1, calculated permeability is much deviated from assumed permeability. Therefore, final equation of scenario 1 is not suitable for the calculation of the well flowing pressure at transient condition.

Percentage of deviation of calculated permeability in scenario 3 lies between 0– 5% for constructed models which have r_a/r_w ratio in between 1 - 250 and k_e/k_a ratio in between 0.1 - 10. Percentage deviation of calculated permeability in scenario 2 lies between 0 – 13% for the same range of ratios r_a/r_w and k_e/k_a.
According to the skin value calculated with these scenarios, both scenarios

are compatible with the real range of skin value.

However, according to the result obtained from the analysis of each scenarios it can be concluded that the, most accurate method to introduce the skin factor in transient condition is presented in scenario 3. Therefore, obtained relationship between skin and formation damage of an oil well at transient condition by scenario 3 (shown in Figure 7) is more accurate than the obtained relationship between skin and formation damage of an oil well at transient state by scenario 2 (shown in Figure 5).

The graph developed in Figure 7 can be used to determine the parameters of damage zone when one knows the permeability of reservoir, radius of the wellbore and skin factor.

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